

REVIEW ARTICLE

Exercise-Induced Protocols to Induce Fatigue in Athletic and Non-Athletic Populations: A Scoping Review

Vishal Shukla¹, Anand Kumar Singh², Kamran Ali³, Kanika Wadhwa⁴

1- MPT Student, G D Goenka University, Faridabad, HR

2- Associate Professor, G D Goenka University, Faridabad, HR

3- Associate Professor, Galgotias University, Noida, UP

4- Assistant Professor G D Goenka University, Faridabad, HR

Corresponding Author: Anand Kumar Singh

ORCID - <https://orcid.org/0000-0002-3238-0680>

ABSTRACT

Fatigue is a natural response to physical exertion, impacting both athletes and non-athletes by affecting performance, muscle function, and recovery. Studying how different exercise protocols induce fatigue is essential for improving training methods, reducing injury risk, and refining rehabilitation strategies. This scoping review explores various exercise protocols designed to induce fatigue in athletic and non-athletic individuals, examining their effectiveness and practical applications. A systematic search was conducted across multiple databases, including PubMed, CINAHL, Scopus, Cochrane Library, and Web of Science, covering research published between 2005 and 2023. Studies that assessed fatigue through structured exercise protocols, such as high-intensity interval training, repeated sprint and jump tests, and resistance exercises, were included in the analysis. Findings indicate notable differences in how fatigue manifests between athletes and non-athletes. Athletes generally show greater endurance and neuromuscular resilience, whereas non-athletes experience a faster decline in strength and coordination. High-intensity fatigue protocols significantly influence movement patterns, postural stability, and proprioception, potentially increasing injury risk, especially in sports requiring rapid changes in motion. Understanding exercise-induced fatigue is key to developing effective training and recovery strategies. Standardized fatigue assessment methods can enhance performance optimization and rehabilitation efforts. Future research should focus on tailored fatigue management strategies, incorporating wearable technology and personalized recovery plans to support both athletic and general populations.

Keywords: Exercise fatigue, fatigue protocols, athletes, non-athletes, neuromuscular function, training adaptation

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INTRODUCTION

Fatigue is a multifaceted condition that affects both physical and mental performance, reducing an individual's ability to sustain activity. It can result from prolonged exertion, metabolic shifts, and changes in neuromuscular function (1,2). In sports science, standardized assessments help analyze exercise-induced fatigue by measuring muscle strength, endurance, and recovery, providing valuable insights for both athletes and non-athletes (3,4).

To better understand physical limitations and recovery strategies, fatigue protocols are developed to mimic the demands of training and competition. These often include high-intensity tests such as VO₂ max assessments or intermittent sprint exercises (5,6). Studying responses to fatigue plays a crucial role in refining training methods and optimizing recovery (7).

A sedentary lifestyle or engaging in low-intensity physical activity is often linked to fatigue in individuals who are not regularly active (8). Research suggests that factors such as chronic health conditions, insufficient physical training, or extended periods of inactivity contribute to feelings of exhaustion in non-athletic individuals (9,10). These differences emphasize the need for tailored fatigue management strategies that address specific physiological demands.

By using standardized exercise protocols to compare fatigue responses across different groups, researchers and healthcare professionals can gain deeper insights into how fatigue manifests in various contexts (13,14). Such findings are valuable not only for enhancing athletic performance but also for guiding rehabilitation strategies for athletes recovering from injuries and for non-athletes undergoing physical therapy (15). Moreover, standardized fatigue assessments play a crucial role in developing targeted interventions for individuals with chronic conditions such as diabetes or cardiovascular disease, helping to improve both performance and overall well-being (16,17).

A scoping review provides an effective way to integrate the various fatigue assessment methods used across different populations. By mapping the existing research, this review will identify the most commonly used exercise protocols and their effects on fatigue in both athletic and non-athletic groups (18,19). Ultimately, this effort aims to establish standardized approaches that can be applied in clinical evaluations and performance enhancement, optimizing training and recovery strategies for a wide range of individuals (20).

MATERIAL AND METHODS

Study Design

To gain a deeper understanding of exercise-induced fatigue in both athletic and non-athletic populations, a scoping review was conducted. This approach is especially useful for examining existing research, identifying key themes, and summarizing findings across diverse study designs and methodologies (21, 22). By utilizing this method, we aimed to explore various fatigue-induction protocols and their specific applications across different groups.

Search Strategy

A comprehensive literature search was conducted across multiple databases, including PubMed, CINAHL, Scopus, Cochrane Library, and Web of Science. To ensure relevance to current practices, only studies published between 2005 and 2023 were considered. The search strategy incorporated Boolean operators and specific keywords such as "exercise-induced fatigue," "fatigue protocols," "athletes," "non-athletes," "exercise testing," and "fatigue assessment" to refine the results effectively. Additionally, reference lists of relevant studies were manually reviewed to identify further pertinent research (23, 24).

Inclusion and Exclusion Criteria

To build a comprehensive synthesis of evidence, this review included studies that specifically examined exercise protocols designed to induce fatigue. The selection criteria encompassed both athletic and non-athletic populations, regardless of age. Studies were required to report either quantitative or qualitative outcomes related to fatigue, such as changes in performance metrics, physiological responses, or subjective fatigue assessments. Research designs considered for inclusion included randomized controlled trials (RCTs), quasi-experimental studies, and observational studies (25). Additionally, only studies that provided detailed descriptions of exercise protocols—covering aspects such as exercise type, intensity, duration, and frequency—were included. To maintain consistency and accessibility, only studies published in English were considered.

Exclusion criteria included studies that:

Studies that addressed fatigue indirectly through non-exercise interventions, such as pharmaceutical, nutritional, or psychological approaches, or that concentrated on fatigue brought on by pathological illnesses, such as chronic fatigue syndrome, were disqualified. Opinion pieces, conference abstracts, reviews, and editorials were also disqualified (26). Additionally, studies without enough methodological information or without pertinent outcome data were not taken into consideration for inclusion.

Study Selection

To eliminate duplicates, all detected records were imported into EndNote X9. Two reviewers individually examined abstracts and titles to determine their applicability. Articles in their whole were examined in light of the inclusion and exclusion criteria. A third reviewer was consulted or discussed in order to resolve any disagreements (27).

Data Extraction and Synthesis

Data extraction was conducted using a standardized form to ensure consistency and comprehensiveness. The extracted data included study characteristics such as author, year of publication, country of origin, and study design. Population demographics, including participants' age, gender, and athletic status, were also recorded. Details of the exercise protocols, such as the type of exercise, intensity, duration, and frequency, were documented meticulously. Additionally, outcome measures, encompassing physiological responses, performance metrics, and subjective fatigue assessments, were captured (28). To enhance the reliability of the process, data extraction was independently performed by two reviewers. Any

discrepancies or conflicts that arose were resolved through discussion and consensus, ensuring the accuracy and completeness of the extracted information (29,30).

Risk of Bias Assessment

Although formal quality assessment is not typically required for scoping reviews, potential biases in included studies were critically appraised. Particular attention was given to conflicts of interest, blinding procedures, and reporting practices to ensure the findings' validity and applicability (31,32).

Analysis and Reporting

The data were synthesized thematically to identify commonalities and variations in fatigue protocols, explore differences between athletic and non-athletic populations, and highlight gaps in the literature (33). The review adhered to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) guidelines to maintain methodological transparency and rigor (34).

RESULTS

The selection process of articles summarized using PRISMA flow diagram (Figure No: 1)

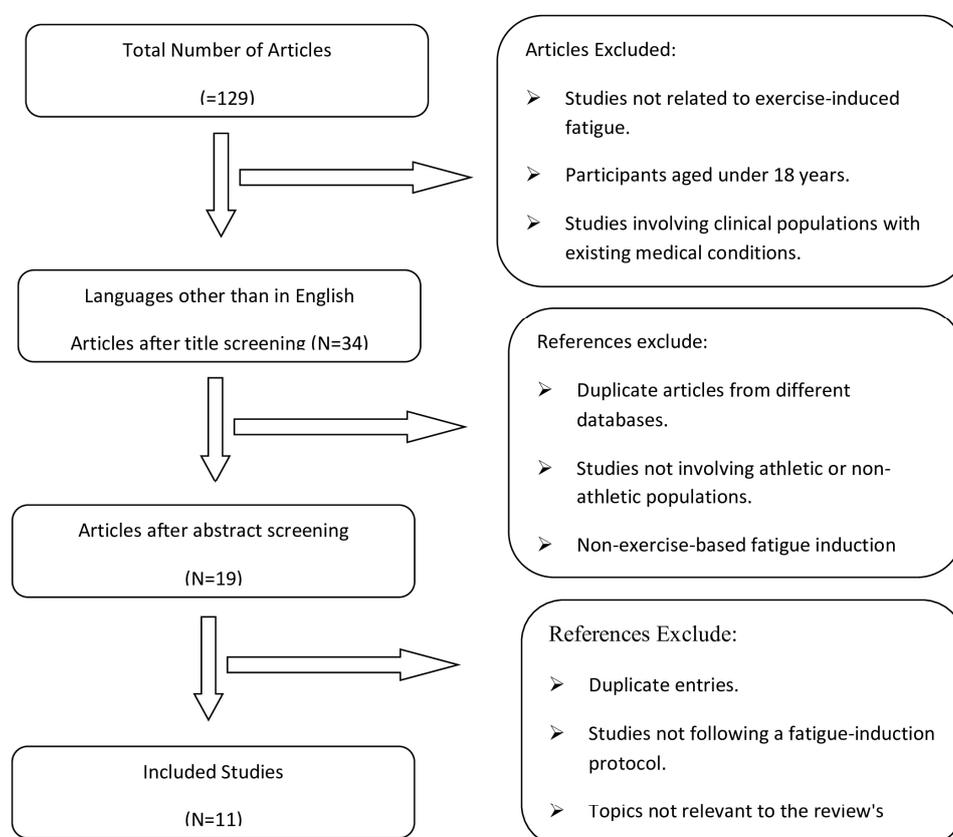


Figure 1. PRISMA Flow Diagram for Selection of Articles

Narrative synthesis of included studies

The body of literature reviewed comprises experimental studies, randomized controlled trials, and cross-sectional investigations that primarily examined the effects of fatigue, loading conditions, and sport-specific interventions on lower-limb biomechanics, neuromuscular function, and athletic performance [35–45]. The majority of studies compared non-fatigued or control conditions with experimentally induced fatigue or specific training interventions, thereby enabling evaluation of fatigue-related neuromuscular and biomechanical adaptations [35,36,38–42,45].

Several studies focused on fatigue induced through functional and sport-specific tasks such as stop-jump maneuvers, agility drills, repeated sprints, simulated match play, heavy resistance loading, and mixed martial arts training [35,36,38–42,45]. Across these investigations, fatigue was consistently shown to alter knee and lower-extremity kinematics and kinetics, particularly during high-risk movements such as landing, cutting, and jumping [35,38,39,42]. These biomechanical alterations included changes in joint

angles, increased impact forces, and modified movement patterns, which collectively suggest an elevated risk of lower-extremity injuries, especially non-contact anterior cruciate ligament (ACL) injuries [35,38,42]. In addition, neuromuscular assessments using electromyography and force-production measures demonstrated significant reductions in muscle activation efficiency and strength following fatigue protocols, particularly in the knee extensors and hamstrings [36,40,45].

Performance-based outcomes were also commonly evaluated. Studies involving repeated sprint ability, jump tests, and simulated match conditions reported notable declines in sprint speed, jump height, and overall functional performance under fatigued conditions [37,41]. Conversely, certain assessment tools, such as the repeated sprint and jump ability test and the five-jump test, demonstrated strong reliability and validity in measuring athletic performance and explosive power [37,43]. Positive associations were observed between field-based jump performance and laboratory measures of muscular power, supporting the practical applicability of these tests in athletic populations [43].

A smaller subset of studies explored intervention-based strategies aimed at improving performance or recovery. For instance, the use of compression garments was associated with improvements in muscular efficacy, proprioception, and perceived recovery when compared to control conditions [44]. These findings suggest that targeted interventions may partially mitigate fatigue-related neuromuscular deficits and enhance post-exercise recovery [44].

Overall, the collective findings indicate that fatigue—whether induced acutely through exercise protocols or cumulatively through sport-specific demands—has a substantial impact on neuromuscular function, lower-limb biomechanics, and athletic performance [35–42,45]. These changes may predispose athletes to injury and performance decrements, emphasizing the importance of fatigue management, injury-prevention strategies, and valid performance assessment tools in both training and competition settings.

Methodological quality and risk of bias assessment

The methodological quality of the included studies varied from moderate to high, with several investigations demonstrating strong internal validity [35,36,38,39,42,44,45]. Most studies clearly defined eligibility criteria and reported comparable baseline characteristics between experimental and control groups [35–45]. Random allocation and concealed allocation were adequately implemented in many randomized controlled trials, particularly in more recent studies, enhancing confidence in the reported outcomes [38,39,42,44].

Blinding procedures were inconsistently applied across the literature. While assessor blinding was reported in several studies [38,39,42,44], subject and therapist blinding were frequently absent or not feasible due to the nature of exercise-based interventions [35–37,40,41,43,45]. Despite this limitation, many studies maintained methodological rigor through standardized testing protocols and objective outcome measures such as motion capture systems, force plates, and electromyography [35,36,38–42,45]. Adequate follow-up and between-group comparisons were reported in the majority of studies, and most provided point estimates along with measures of variability, allowing for meaningful interpretation of results [35–39,41,42,44,45]. However, some studies—particularly experimental and cross-sectional designs—lacked randomization, concealed allocation, or intention-to-treat analysis, thereby increasing the potential risk of bias [37,40,43].

Overall, a substantial proportion of the included studies demonstrated a low risk of bias, particularly those employing randomized controlled designs with comprehensive reporting of methodological procedures [38,39,42,44]. A smaller number of studies exhibited higher risk of bias due to limitations in randomization, blinding, or incomplete methodological reporting [37,40,43]. Nevertheless, the overall quality of evidence supports the reliability of the conclusions drawn, with stronger confidence placed on findings from well-designed randomized controlled trials.

DISCUSSION

Fatigue has been widely recognized as a critical factor influencing lower-limb biomechanics, neuromuscular function, and athletic performance. Numerous studies have demonstrated that fatigue alters kinematic and kinetic patterns, thereby increasing injury susceptibility and reducing movement efficiency [35–45]. One consistent finding across the literature is the detrimental effect of fatigue on knee kinetics and kinematics during high-intensity activities. Chappell et al. reported that fatigue significantly increased anterior cruciate ligament (ACL) strain during stop-jump tasks, thereby elevating the risk of ligamentous injury [35]. Similarly, Xia et al. showed that fatigue induced through running and jumping protocols altered impact forces and lower-extremity kinematics during drop landings, further emphasizing the biomechanical consequences of fatigue on joint loading and stability [42].

Neuromuscular fatigue has also been shown to adversely affect movement mechanics during agility-based and sport-specific tasks. Cortes et al. demonstrated that fatigue induced by a functional agility

protocol resulted in significant alterations in lower-extremity mechanics, potentially increasing the risk of inefficient movement patterns and injury [38]. Quammen et al. further reported that different fatigue protocols led to distinct changes in motion patterns during stop-jump tasks, highlighting the influence of fatigue on neuromuscular coordination and joint stabilization strategies [39]. In addition, Walker et al. observed prolonged reductions in force production of the knee extensors following isotonic heavy-resistance loading, underscoring the role of fatigue in diminished muscular efficacy [36].

Performance impairments associated with fatigue have been extensively investigated, particularly in high-intensity activities such as sprinting and jumping. Buchheit et al. demonstrated that repeated sprint and jump ability tests are reliable and valid tools for quantifying fatigue-related declines in athletic performance, with clear reductions observed in sprint speed and jump height under fatigued conditions [37]. These findings were supported by Dal Pupo et al., who reported significant decrements in sprint performance and altered lower-limb kinematics following a simulated futsal match, reflecting the cumulative effects of match-related fatigue [41]. Similarly, Ben Ayed et al. found that fatigue negatively influenced explosive power in youth volleyball players, as evidenced by reduced performance in the five-jump test [43].

Beyond biomechanical and performance-related effects, fatigue also impacts proprioception and postural control. Ismaeli demonstrated that a slow oxidative fatigue protocol significantly reduced hamstring strength and functional performance, which may compromise joint stability and neuromuscular control [40]. Fatigue-related proprioceptive deficits have been associated with impaired balance and increased risk of joint misalignment. In this context, Hong et al. reported that the use of compression garments improved muscular efficacy, proprioception, and recovery, suggesting a potential strategy to attenuate fatigue-induced neuromuscular impairments [44].

Fatigue plays a particularly critical role in high-intensity combat sports such as mixed martial arts (MMA). Giboin and Gruber showed that MMA-specific training protocols induced significant neuromuscular fatigue, resulting in reduced force production and movement efficiency [45]. These findings reinforce the broader evidence that intense, sport-specific training loads can substantially impair neuromuscular function across diverse athletic populations.

Effective fatigue management is therefore essential to reduce injury risk and maintain optimal performance. The literature supports the implementation of targeted recovery strategies, including neuromuscular training, proprioceptive exercises, and supportive interventions such as compression garments [38,40,44]. Such approaches may help mitigate fatigue-related deficits, enabling athletes to sustain performance and reduce injury risk during training and competition.

LIMITATIONS

The included studies demonstrated substantial heterogeneity in study design, fatigue protocols, participant characteristics, and outcome measures, limiting direct comparison across studies. Variations in fatigue induction methods and assessment tools may have influenced neuromuscular and biomechanical outcomes. Most studies predominantly included male participants, restricting the generalizability of findings to female populations. Differences in measurement techniques may have introduced variability in reported results. Additionally, small sample sizes and limited blinding in some studies may have increased the risk of bias.

FUTURE DIRECTIONS

This analysis sheds light on the connection between sports performance and fatigue; however, certain aspects still require further investigation. Long-term studies could offer a deeper understanding of how fatigue influences injury risk and performance adaptations over time. Additionally, incorporating real-time monitoring tools, such as wearable sensors and EMG feedback, may provide more accurate insights into neuromuscular fatigue in high-intensity sports environments. Lastly, developing personalized fatigue management strategies—such as data-driven rehabilitation protocols and customized recovery plans—could enhance athletic performance while reducing the risk of injuries.

CONCLUSION

This scoping review highlights the substantial impact of fatigue on biomechanics, neuromuscular function, and sports performance. The evidence underscores the need for targeted interventions to mitigate fatigue-induced impairments and enhance recovery strategies. By advancing our understanding of fatigue mechanisms and implementing evidence-based training approaches, athletes and practitioners can improve performance outcomes while reducing injury risks. Future research should focus on refining

fatigue assessment methods and developing personalized fatigue management protocols to support optimal athletic performance.

COMPETING INTERESTS

The authors have declared that no competing interest exists.

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